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PRODUCTION OF HIGH TRANSVERSE ENERGY EVENTS IN pp COLLISIONS AT 400 GeV/c

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Abstract

High transverse energy events produced in pp collisions at 400 GeV/c were studied using the large acceptance Fermilab Multiparticle Spectrometer. The cross sections for such interactions exhibit an exponential dependence on transverse energy with values of the slope increasing with the decreasing azimuthal acceptance of the trigger. The majority of events selected with full azimuthal acceptance are non-planar; hence they do not show jet-like event structure. The fraction of planar events is small and remains constant as a function of transverse energy.

The hadronic production of high transverse momentum (high p_t) secondaries is expected to result from the hard collision of hadronic constituents rather than from a collision between hadrons as a whole.[1] Such production may be considered as being due to the scattering and subsequent fragmentation of partons into 'jets'.[2] If so, an understanding of single particle production is complicated by the fact that detailed knowledge of 'jet' fragmentation is necessary. To avoid this complication, several experiments[3-5] have attempted to trigger on 'jets' by demanding that a large value of p_t be confined to a small volume of phase space rather than to a single particle. The drawback of this scheme is that prior knowledge of the 'jet' size is essential. Large acceptance experiments, such as NA5 at CERN[6] and now E557 at Fermilab, have attempted to overcome this latter difficulty by relaxing the geometrical phase space requirement while retaining the necessity for a large value of transverse energy ($E_t \approx \Sigma|p_t|$ for relativistic secondaries) in an event. The NA5 group has recently reported[6] that cross sections for high E_t πp and pp collisions at 300 GeV/c are substantially larger than predictions from the four-jet QCD models and that the majority of events do not show jet-like structure. In this letter results from the E557 experiment are presented.

The E557 experiment was performed using 400 GeV diffractively produced protons from the M6W beam line at Fermilab. The beam was incident on a 45 cm H_2 target followed downstream by two interchangeable metal foils of Al, Cu or Pb.

The detection apparatus consisted of the Fermilab Multiparticle Spectrometer[4,7,8]. Multiwire proportional chambers (34 planes of 8500 wires) and magnetostrictive spark chambers (24 planes) detected charged particles. Their momenta were measured using a spectrometer magnet that provided a 0.2 GeV/c p_t

kick. Downstream of the tracking chambers was placed a 2.3 x 3.1 m^2 highly segmented calorimeter[7] consisting of 280 modules arranged into three sections: The upstream section, which consisted of 126 lead-scintillator sandwiches, (16 radiation lengths (L_r) and 0.8 absorption lengths (L_a)), primarily measured the energy of electromagnetic particles. It was followed by two hadronic sections of 126 and 28 iron-scintillator sandwiches respectively (63 L_r and 7.5 L_a combined). The distance from the center of the hydrogen target to the front face of the calorimeter was 9.4 m. The calorimeter served both as a trigger (see below) and as a detector of neutral and charged particles.

The geometrical acceptance of the calorimeter was complete in azimuth for the polar angle range $56° < \theta^* < 114°$ as measured in the proton-proton center-of-mass frame (fig. 1); the overall acceptance was estimated to be equivalent to 2π azimuthal acceptance for $47° < \theta^* < 125°$. This corresponds approximately to a c.m. rapidity y^* range $- 0.65 < y^* < 0.84$.

The apparatus was triggered in several ways. Firstly, an inelastic collision was detected. This constituted the 'interacting beam trigger' and it was sensitive to approximately 90% of the total inelastic pp cross section. The other triggers consisted of the 'interacting beam' trigger with an additional requirement that at least a certain amount of transverse energy was present in some preset region of the calorimeter. For all triggers the incident proton was required to be unaccompanied by another beam particle within ± 130 ns.

In order to trigger, E_t for each module was formed by weighting its output by the sine of its polar angle at the target. E_t sums for several different configurations of calorimeter modules were formed simultaneously. Data from three configurations are presented here: full azimuthal acceptance

('2π'), two $2\pi/5$ apertures diametrically opposed to each other ('$4\pi/5$') and small aperture ('$\pi/5$'), with approximate acceptances of 7.8, 2.8 and 0.70 steradians in the proton-proton center-of-mass frame, respectively (Fig. 1).

To determine the absolute E_t scale the calorimeter was calibrated twice, before and after the 18-day data run, by directing a 20 GeV/c beam of electrons and hadrons into each module.

In this analysis the spectrometer was used only to determine the position of the interaction vertex. The vertex resolution was $\sigma(z) \approx \pm$ 4mm, providing a clean hydrogen-nuclear target separation. The E_t sums for a given event were calculated off-line using an exact vertex position. A Monte-Carlo simulation, based on the observed spectra of particles, was employed to unfold the energy resolution of the calorimeter(7) and to correct for the effects of the magnetic field. The total uncertainty of the E_t scale from the calibration and other sources was estimated to be $\sigma(E_t)/E_t = \pm 5\%$.

The set of pp interactions used in this analysis consisted of 32K, 16K, 4K, and 3.5K events taken with the interacting beam,'2π', '$4\pi/5$' and '$\pi/5$' triggers, respectively.

In Fig. 2 the pp cross sections are shown as a function of the transverse energy for the triggers with the '2π', '$4\pi/5$' and '$\pi/5$' azimuthal acceptances. Cross sections for lower values of E_t (approximately the lower half of the E_t range for a given trigger) were measured using the interacting beam data. At larger E_t cross sections were obtained by imposing several E_t thresholds.(8) The studied range of E_t for the '2π' trigger extended up to 24 GeV (the kinematic limit is at 27.4 GeV).

For large E_t the data fit well to the function: $d\sigma/dE_t \sim e^{-\alpha E_t}$ with values of the slope α equal to 0.85 ± 0.02, 1.25 ± 0.05 and 2.5 ± 0.1 for '2π', '$4\pi/5$' and '$\pi/5$' triggers, respectively. The strong dependence of the cross sections on the aperture of the trigger, previously observed by the NA5 group[6], therefore is confirmed.

The 2π cross sections from E557 are substantially larger than the corresponding NA5 data;[6] they also exhibit a weaker E_t dependence. However, the cross sections for the two experiments plotted as functions of the variable $x_t = E_t/\sqrt{s}$ have almost identical slopes.[8] No conclusions based on the normalization differences between the two experiments can be drawn since the E_t scales in both experiments have 5% errors and slightly different regions of phase space were covered.

Similar dependence of cross sections on E_t and on the aperture of the trigger has been found for the interacting beam type events by R416 and R807 experiments at the ISR[9] and it appears to persist also at $\sqrt{s}$ = 540 GeV.[10] However, these analyses have covered only regions of small x_t, $x_t < 0.2$.

Event structure was studied employing the variable planarity (P), as used by the NA5 group.[6] In the plane transverse to the beam direction the principal axis of an event was found and the p_t vector for each module was decomposed into components parallel and transverse to this axis. Denoting the sum of the squared components along and transverse to the principal axis as A and B, then planarity is defined as $P = (A-B)/(A+B)$. For pencil-like back-to-back jets, P approaches 1 while for large multiplicity isotropic events it approaches 0. Fig. 3a shows the observed planarity distributions for the '2π' data sample. The majority of events are non-planar. Fig. 3b shows the variation of the mean planarity with E_t. For $E_t < 6$ GeV the planarity rises because of the very low multiplicity of secondaries hitting the calorimeter. Above E_t = 6 GeV the planarity indicates a mostly isotropic distribution of secondaries unaffected by increasing E_t.

The fraction of high planarity events, 9% for $P > 0.7$, stays constant with E_t also (Fig. 3c). Consequently, the production of planar events exhibits the same exponential dependence on E_t as the cross sections for the '2π' acceptance data.

The events selected with smaller aperture triggers are much more planar than the 2π data (Fig. 3a,b) and their mean planarity increases rapidly with E_t of the trigger, as might be expected from previous experiments with limited acceptance.[3-5]

Planar events selected from the '2π' trigger data are characterized by a relatively small multiplicity of secondaries observed in the calorimeter. Indeed, mean planarity rapidly increases as a function of transverse energy per "energy cluster"[8] seen in the calorimeter and the events start to exhibit "jet-like" characteristics. However, such behavior of planarity is also qualitatively predicted by a longitudinal phase space model with secondaries emitted isotropically in the azimuth.

At present it is difficult to estimate the exact fraction of events that possess "jet-like" qualities but it appears to be less than 5% of the total '2π' data sample with high E_t. This upper limit is consistent with the cross sections for the jet production predicted by the four-jet QCD models.[6, 11] The majority of events would then be due to low-p_t type pp collisions.[12] However, a recent QCD approach[11] suggests that the large cross sections seen with the '2π' acceptance trigger are due to trigger bias which favours events where the constituents active in the hard scattering process radiate large number of bremmstrahlung gluons.

We conclude that the production of events with large values of transverse energy is far more frequent than that expected from four-jet QCD predictions. The majority of events are non-planar. The fraction of planar events is small and remains constant as a function of transverse energy, even for pp collisions with more than 75% of the initial pp c.m. energy appearing as E_t.

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Figure Captions

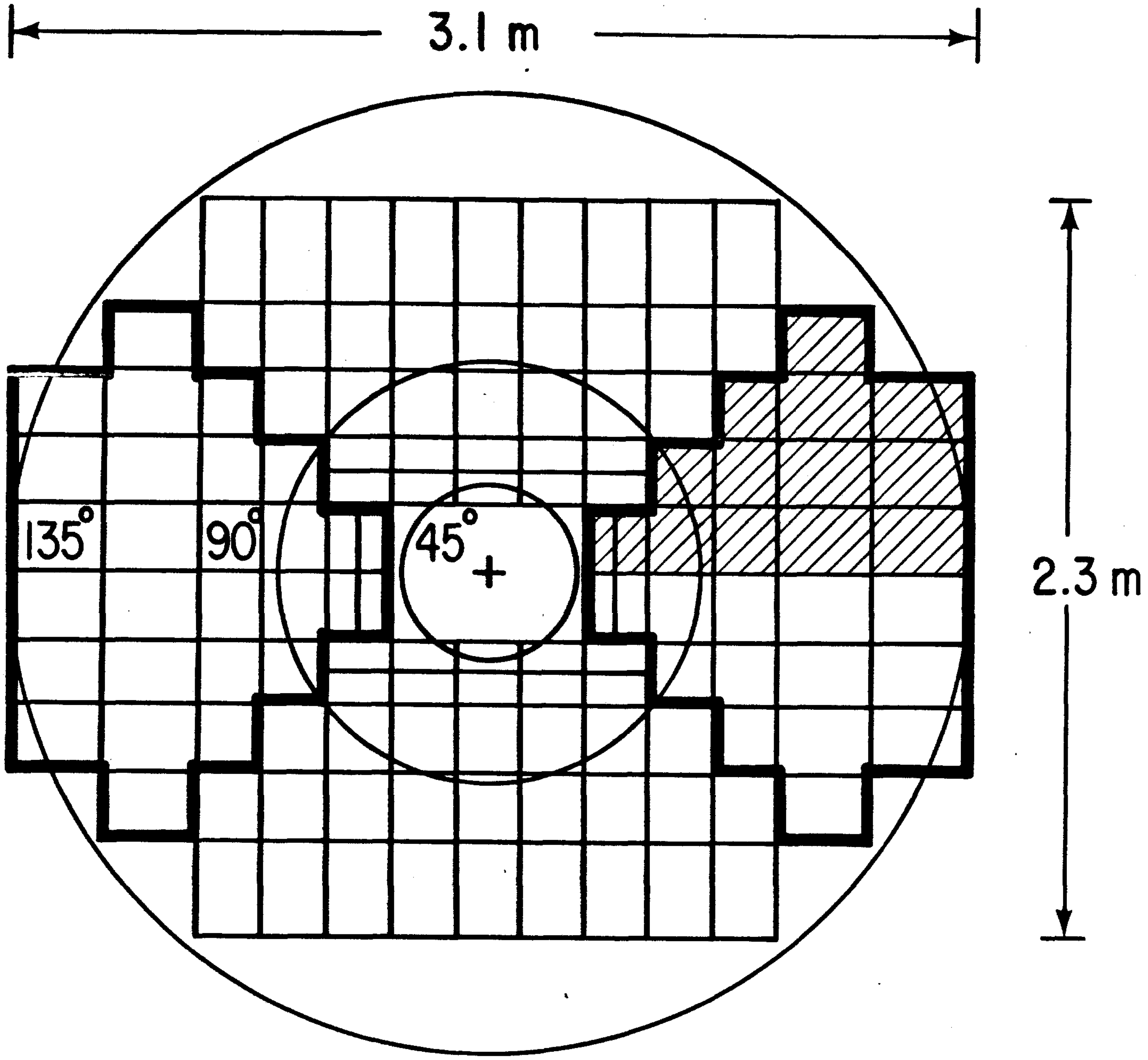
Fig. 1 Segmentation of the electromagnetic and front hadron sections of the calorimeter. Circles represent c.m. polar angles for massless particles produced in pp interactions at 400 GeV/c as seen at the face of the calorimeter. The thick line and shaded area indicate boundaries of the '$4\pi/5$' and '$\pi/5$' triggers, respectively (see text).

Fig. 2 Cross sections obtained with large ($\Delta\phi \simeq 2\pi$: open circles), medium ($\Delta\phi \simeq 2 \times 2\pi/5$: triangles) and small ($\Delta\phi \simeq \frac{\pi}{5}$: squares) azimuthal acceptances as a function of transverse energy of the trigger, E_t. The error on the E_t scale is $\pm$ 5%. The lines represent exponential fits to the data.

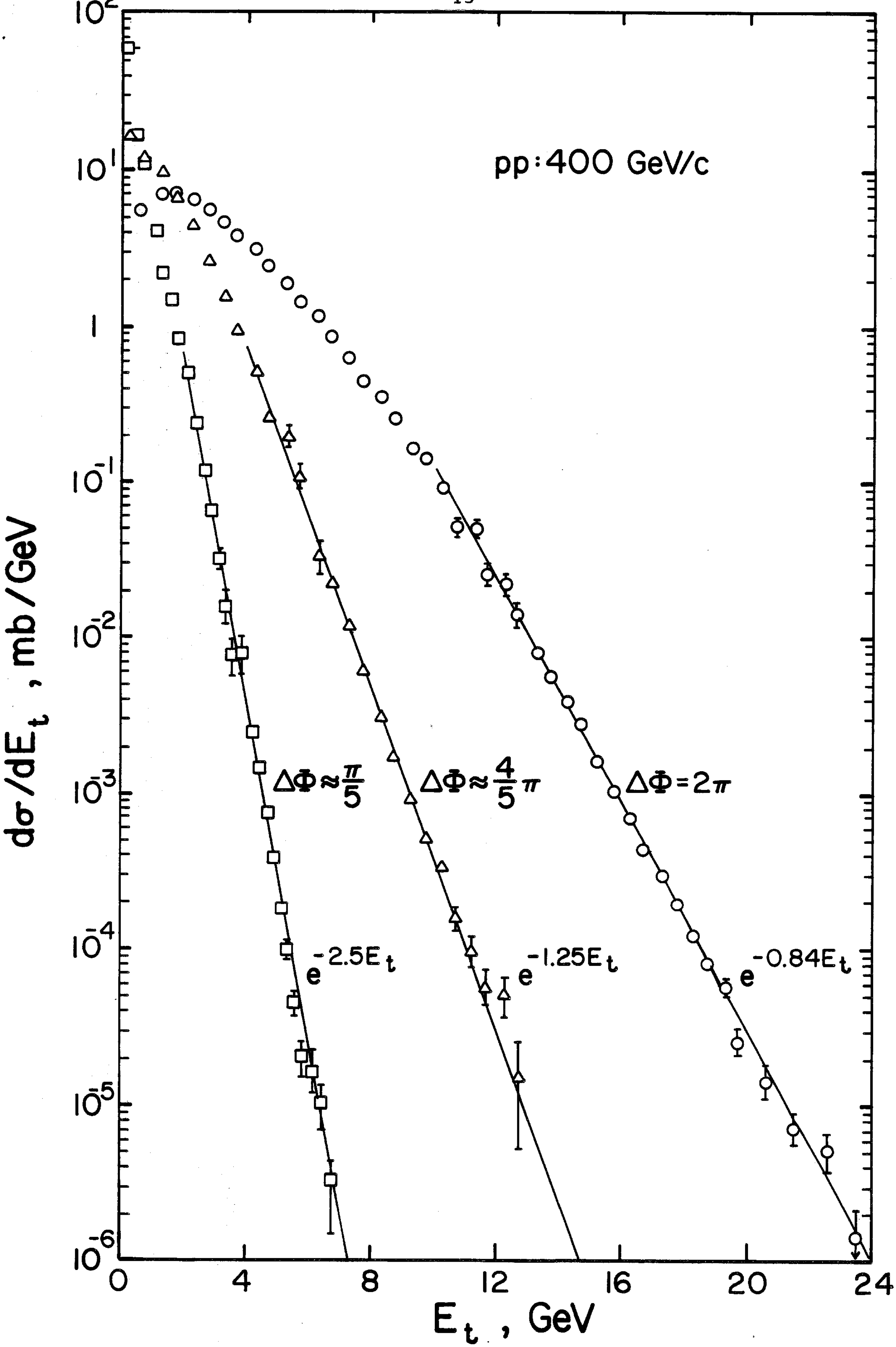
Fig. 3(a) Planarity distributions for events obtained with various triggers: '2π' with $E_t > 15$ GeV-full line, '$4\pi/5$' with $E_t > 8$ GeV - dashed line and '$\pi/5$' with $E_t > 4$ GeV - dotted line.

(b) mean planarity as a function of E_t. Symbols are the same as in Fig. 2.

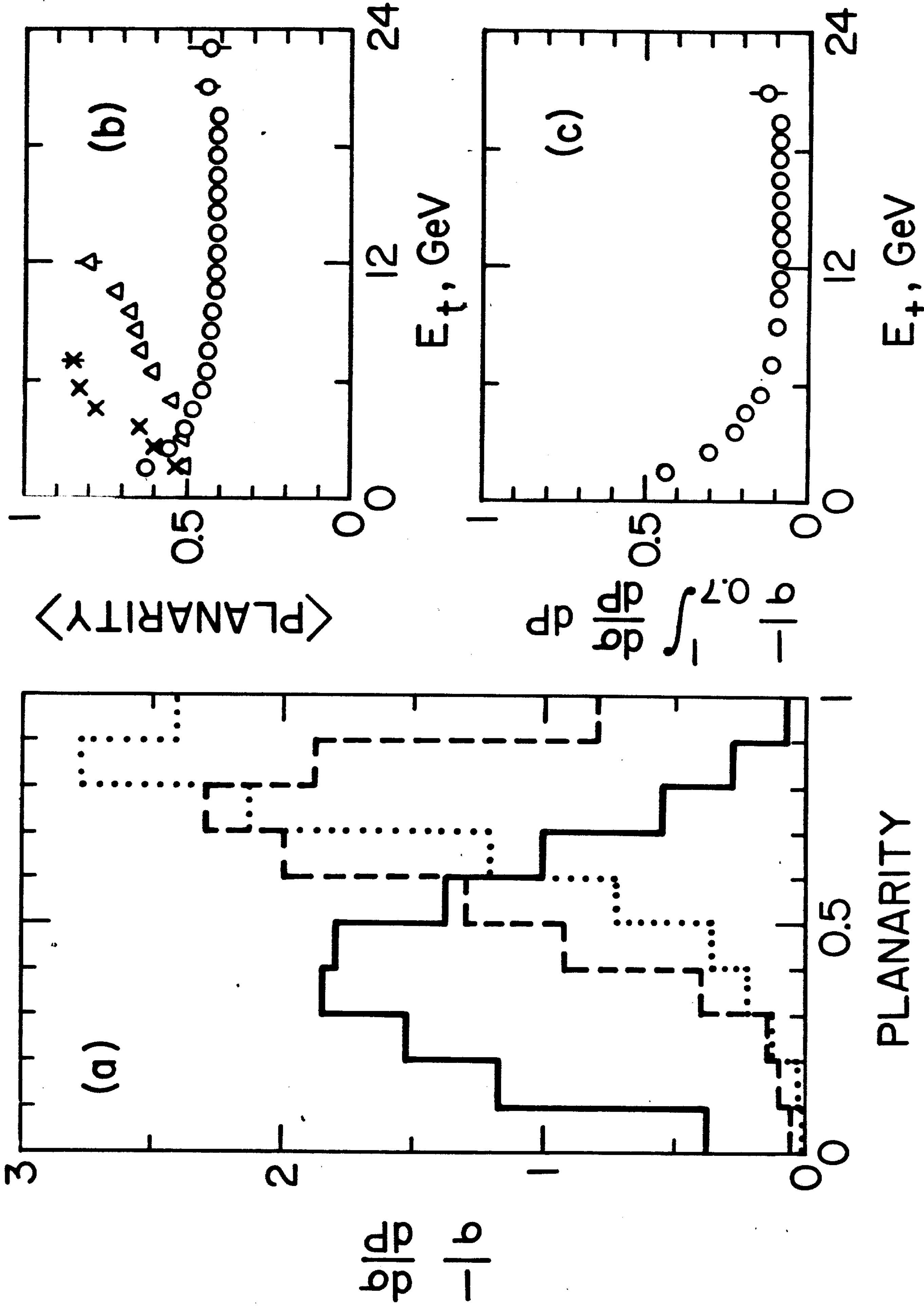
(c) fraction of events with planarity greater than 0.7 as a function of E_t for the '2π' data.



3.1 m
2.3 m
135°
90°
45°



pp: 400 GeV/c
$d\sigma/dE_t$, mb/GeV
E_t , GeV
$\Delta\Phi \approx \frac{\pi}{5}$
$\Delta\Phi \approx \frac{4}{5}\pi$
$\Delta\Phi = 2\pi$
$e^{-2.5E_t}$
$e^{-1.25E_t}$
$e^{-0.84E_t}$



(a)
(b)
(c)
PLANARITY
⟨PLANARITY⟩
$\frac{1}{\sigma}\frac{d\sigma}{dP}$
$\frac{1}{\sigma}\int_{0.7}^{1}\frac{d\sigma}{dP}\,dP$
E_t, GeV
0
0.5
1
2
3
12
24